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FFG-7 Ship Motion and Airwake Trial: Part 1 - Data Processing Procedures

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DEPARTMENT OF DEFENCE

DEFENCE SCIENCE AND TECHNOLOGY ORGANISATION

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Aeronautical and Maritime Research Laboratory

ABSTRACT

Technical Report

A trial to measure ship motion and airwake has been carried out aboard an 'Adelaide' class FFG-7 frigate. Data processing procedures are described which take the raw measured data from the data acquisition system, convert them to imperial units, and correct the Gill anemometer data for non-cosinusoidal response to angle-of-attack variation. A method of salvaging data corrupted by high frequency signals is also presented, along with a discussion of further data processing required to enable the results to be used as a data base for a computer simulation of the Sikorsky S-70B-2 helicopter and FFG-7 combination.

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Ashley Arney graduated from the University of Sydney in 1981, having obtained an Aeronautical Engineering Degree, with honours. Since commencing employment at the then Aeronautical Research Laboratories in 1982, he has been involved with the mathematical modelling of the performance and flight dynamics of a wide range of helicopters. He has also obtained extensive experience in trials, data processing, and the use of such data for development of the appropriate mathematical model. More recently he has been involved in modelling the S-70B-2/FFG-7 combination as employed by the Royal Australian Navy, and gathering data for development purposes.

CONTENTS

EXECUTIVE SUMMARY

A helicopter/ship computer model has been developed to simulate the complex interactions in the dynamic interface between ship and helicopter, in particular between the 'Adelaide' class FFG-7 frigate and Sikorsky S-70B-2, a combination used by the Royal Australian Navy (RAN). The model includes helicopter flight dynamics and engine dynamics, undercarriage dynamics, the RAST (Recovery Assist, Secure, and Traverse) system, ship motion, and a representation of the airwake. The original ship airwake model used in the simulation code has been studied and found to have marked differences between the calculated and measured airwake velocities, when applied to an FFG-7 frigate.

From 18 to 21 September 1989, a trial was undertaken aboard HMAS Darwin, an 'Adelaide' class frigate, fitted with stabilisers and RAST equipment. The objective of the trial was to measure the ship motion and airwake over the flight deck for a variety of wind-over-deck velocities for use as a data base in the helicopter/ship simulation code.

This report gives a brief description of the scope of the trial and details of the data gathering aboard ship, and demonstrates the use of data reduction software. A mast mounted on a movable base was fitted with three sets of tri-axial Gill anemometers, and was used to measure the wind velocities over the flight deck. Data processing procedures are described which take the raw measured data from the data acquisition system, convert them to imperial units, and correct the Gill anemometer data for non-cosinusoidal response to angle-of-attack variation.

Examination of the data indicate that, for some of the test runs, high frequency (HF) interference from the ship's HF emitters occurred. A method of salvaging data corrupted by the HF signals is also presented, along with a discussion of further data processing required to enable the results to be used as a data base for a computer simulation of the S-70B-2 and FFG-7 combination.

1. INTRODUCTION

In 1987, the Defence Science and Technology Organisation (DSTO) obtained a helicopter/ship computer simulation model from the US Naval Air Warfare Center (NAWC) Aircraft Division (previously known as the Naval Air Test Center). The code was obtained under the auspices of The Technical Cooperation Program (TTCP). The model can be used to simulate the complex interactions in the dynamic interface between ship and helicopter, in particular between the 'Adelaide' class FFG-7 frigate and Sikorsky S-70B-2, a combination used by the Royal Australian Navy (RAN). The model includes helicopter flight dynamics and engine dynamics, undercarriage dynamics, the RAST (Recovery Assist, Secure, and Traverse) system, ship motion, and a representation of the airwake (Ref. 1). The model has been substantially modified from its original state and already has been used to assess a number of operational problems for the RAN (Ref. 2). Its main use is expected to be assisting the RAN with developing safe operating envelopes for helicopters operating from ships (Ref. 3).

The original ship airwake model used in the simulation code has been studied by Erm (Ref. 4) and found to have marked differences between the calculated and measured airwake velocities, when applied to an FFG-7 frigate. These differences are attributed to the origins and subsequent development of the model, in which measurements based on different class ships were used, with arbitrary changes then being made to improve the accuracy of a real-time simulator.

From 18 to 21 September 1989, a trial was undertaken aboard HMAS Darwin, an 'Adelaide' class frigate, fitted with stabilisers and RAST equipment. The objective of the trial was to measure the ship motion and airwake over the flight deck for a variety of wind-over-deck velocities (the trials instructions are detailed in Ref. 5) for use as a data base in the acquired simulation code. The instrumentation package, including motion sensors and anemometers, is reported in Ref. 6 and the data were recorded using a data acquisition system (Ref. 7) developed by Air Operations Division (AOD). Prior to the trial, calibrations were made for (a) anemometers in the AOD low-speed wind tunnel, (b) angular rates on a rate table, and (c) attitudes on a tilt table. Just before sailing, measurements were taken while the ship was alongside. The purpose of this was to provide procedural practice for the trials team and obtain data for the zero ship motion case as a baseline when investigating effects of ship motion for the 'at sea' cases.

The results of the trial to measure ship motion and airwake are documented in three parts. Part I (this one) gives a brief description of the scope of the trial and details of the data gathering aboard ship, and demonstrates the use of data reduction software developed to obtain processed data in imperial units from the raw measured data. Part II (Ref. 8) outlines a process that has been developed whereby the ship attitudes, velocities, and displacement, including initial conditions, may be determined through parameter estimation. The use of software developed to remove the calculated ship motion from the measured airwake data is also described. Part III (Ref. 9) presents the airwake mean flow and turbulence levels over the flight deck of the FFG-7.

Imperial units are adopted in this report since (a) they are used exclusively by research workers in the US with whom AOD is collaborating and (b) both the helicopter and ship referred to are built in the US to imperial unit specifications.

2. SCOPE OF SHIP MOTION AND AIRWAKE TRIAL

2.1 Relative Wind Conditions

A comprehensive envelope of relative wind speed and direction was required to establish a data base for the airwake model of the simulation code. The trial was programmed to take place during a transit from Australia to New Zealand, when suitable weather conditions could be expected. Due to the uncharacteristically benign conditions actually encountered during the voyage across the Tasman Sea, a somewhat limited envelope was achieved. Figure 1 details the required and measured relative wind envelopes. The FFG-7 is essentially symmetrical about the centreline and small assymetries (such as the Landing Safety Officer's station) were assumed to have a negligible affect on the flow over the flight deck. Relative winds to starboard were chosen to facilitate ease of data gathering.

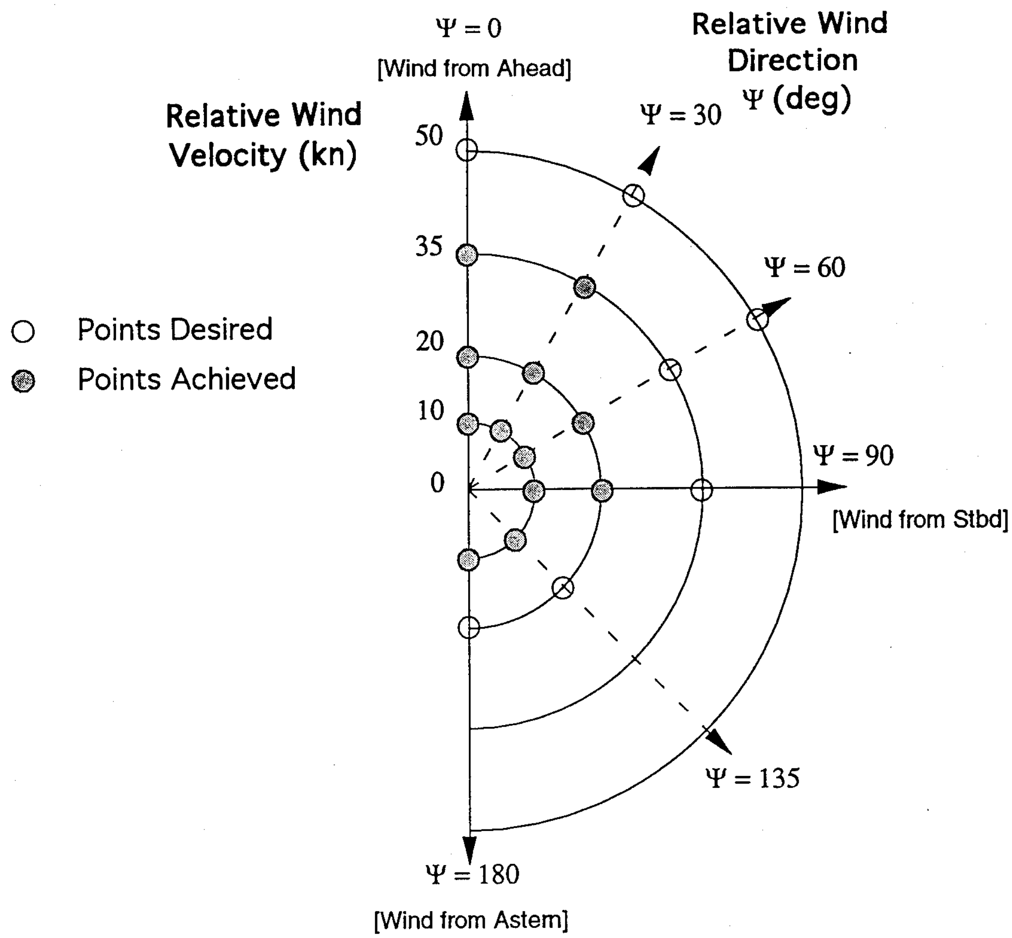

Figure 1. Relative Wind Envelope for Ship Motion and Airwake Trial

2.2 Data Acquisition System

The data were recorded using the Versatile Airborne Data Acquisition and Replay (VADAR) system. The system was used to acquire data from anemometers, temperature sensors, accelerometers, attitude devices, and rate gyros, as well as data from the ship instrumentation (synchros). VADAR recorded 41 data channels for the shipboard trials. A short description is given below (see Refs 5 to 7 for more details).

VADAR was based on an AT Compaq Portable III Computer (PC) fitted with analogue-to-digital and synchro-to-digital cards. Software was written to enable the user to configure the system to record up to 32 analogue channels, 6 synchro channels, and 8 digital channels at the desired sampling frequency.[1] A graphical interface allowed the user to view the data numerically as they were sampled or view selected channels graphically as time histories. The user had the choice of viewing the data in either raw form or converted to imperial units using calibrations made prior to the trial. During a recording run, data were written into Random Access Memory (RAM) to allow for high sampling frequencies. When the run was completed, the data were automatically transferred from volatile RAM to the computer hard disk with a filename based on current time and date. The files were then transferred from the hard disk to floppy disks.

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1 The sampling frequency of individual channels may differ according to the capability of the relevant instrument and the expected rate of change of the measured parameter. Note that if different sampling frequencies are chosen for a particular application, they should have a least common denominator for optimum storage of the data. For example, if data are required at frequencies of 5 Hz and 20 Hz, all data are acquired by recording at 20 Hz. However, for frequencies of 3 Hz and 20 Hz, the data must be recorded at 60 Hz.

PC Channels A1 to A32 are the analogue input channels, DI1 to DI8 are the digital input channels, and SY1 to SY6 are the synchro input channels. For PC Channels A1 to A32, the analogue-to-digital card has a range of ± 5 volt and the converter has a resolution of 12 bits. Therefore, for a nominal gain of 1, each bit is equal to 10/4096 (2.441E-3) volt. For example, if channel A2 had a value of -600, this would be reading -600 x 2.441E-3 = -1.464 volt. PC Channels DI1 to DI8 simply read either 1 or 0, while the synchro channels SY1 to SY6 read from 0 to 360 degrees.

The channels recorded are listed in Tables 1 to 3 below.

Table 1. Ship Motion and Airwake Analogue Channels

Chan No.	PC Chan	Channel Label
1	A01	Mast Direction Low 9
5	A05	Ship Pitch Attitude
6	A06	Ship Roll Attitude
7	A07	Ship Pitch Rate
8	A08	Ship Roll Rate
9	A09	Ship Yaw Rate
10	A10	Ship Vertical Acceleration
11	A11	Ship Lateral Acceleration
12	A12	Ship Longitudinal Acceleration
13	A13	Mast Temperature Top
14	A14	Mast Temperature Mid
15	A15	Mast Temperature Low
16	A16	Port Cup Anemometer Speed
17	A17	Port Cup Anemometer Direction
18	A18	Starboard Cup Anemometer Speed
19	A19	Starboard Cup Anemometer Direction
20	A20	Mast Speed Top 1
21	A21	Mast Speed Top 2
22	A22	Mast Speed Top 3
23	A23	Mast Speed Mid 4
24	A24	Mast Speed Mid 5
25	A25	Mast Speed Mid 6
26	A26	Mast Speed Low 7
27	A27	Mast Speed Low 8
28	A28	Mast Speed Low 9
29	A29	Mast Longitudinal Slant
30	A30	Mast Lateral Slant
31	A31	Aerovane Speed
32	A32	Aerovane Direction

Table 2. Ship Motion and Airwake Digital Channels[1]

Channel Number	PC Chan	Channel Label
33	DI1	Mast Direction Top 1
34	DI2	Mast Direction Top 2
35	DI3	Mast Direction Top 3
36	DI4	Mast Direction Mid 4
37	DI5	Mast Direction Mid 5
38	DI6	Mast Direction Mid 6
39	DI7	Mast Direction Low 7
40	DI8	Mast Direction Low 8

Table 3. Ship Motion and Airwake Synchro Channels

Channel Number	PC Chan	Channel Label	Comments
51	SY1	Ship Heading	0 = North, 90 = East
52	SY2	Ship Speed	0 = 0 kn, 360 = 40 kn
53	SY3	Ship Anemometer Speed	0 = 0 kn, 360 = 100 kn
54	SY4	Ship Anemometer Direction	0 = from bow, 90 = from starboard

2.3 Anemometer Details

The 'freestream' velocity measured by the ship anemometer[2] was used as the reference for the relative wind velocity. Two cup anemometers were placed on either side of the rear of the flight deck, and a Young aerovane anemometer was mounted on a 13.33 ft mast slightly offset from the centre and aft of the flight deck. A mast mounted on a movable base was fitted with three sets of tri-axial Gill anemometers, and was used to measure the wind velocities over the flight deck at thirteen different positions. At each of the thirteen positions, a 90 second recording run was made so as to enable ship motion effects to be accounted for. Figure 2 gives the dimensions and layout of the mobile anemometer mast,[3] and Figure 3 shows the dimensions of the aerovane and cup anemometers.

1 Digital channels have a value of either 1 or 0. In this case, a value of 1 indicates wind flowing out of the propeller, and a value of 0 indicates wind into the propeller.

2 The boundary layer of the ambient wind may extend beyond the height of the main mast, in which case the ship anemometer will not be measuring the true freestream velocity.

3 The configuration of the anemometers on the mobile mast, as used for the actual trial (Fig. 2), was changed from that shown in Ref. 5 because it was determined to be preferable to have the three Gill anemometer array longitudinal axes coincident rather than offset.

Figure 4 details the thirteen positions at which recordings were made, as well as the positioning of the aerovane and cup anemometers.[1]

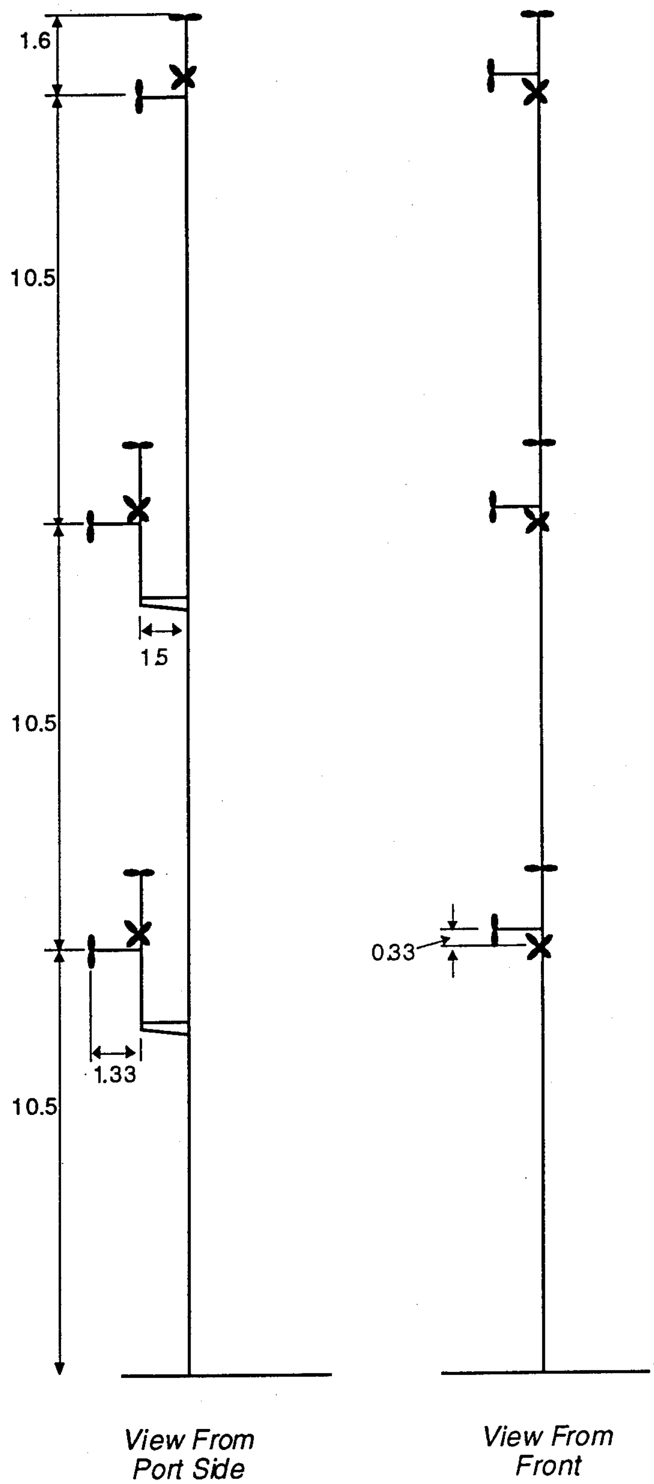


Figure 2. Mobile Anemometer Mast (Dimensions in Feet)

---

1 Upon examination of the flight deck it was found that certain deck fittings interfered with the mobile mast at some of the grid locations. The grid pattern was therefore modified as indicated by Fig. 4 when compared with the desired pattern of Ref. 5.

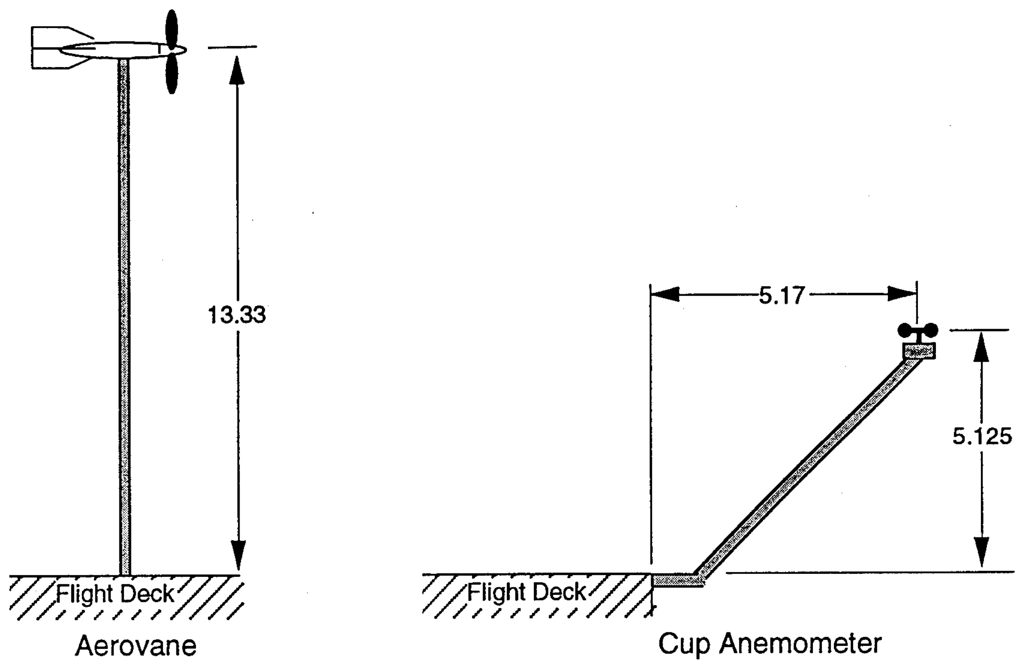


Figure 3. Aerovane and Cup Anemometers (Dimensions in Feet)

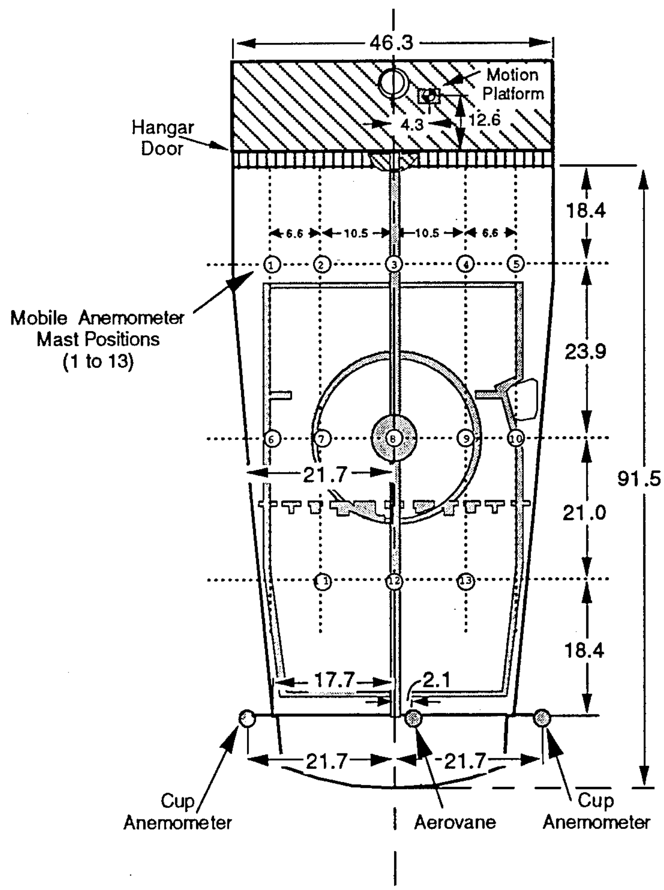


Figure 4. Anemometer Positions (Dimensions in Feet)

3. DATA GATHERING

A brief description of the data gathering processes performed while the ship was alongside and at sea is now given. A record of the computer files for each condition, together with associated comments, is given in Appendix A.

3.1 Alongside

Before setting to sea, the ship motion platform was installed in the starboard hangar (Fig. 4) and adjusted so that a spirit level indicated the platform was approximately level in earth axes. To relate the measured attitudes to the ship datum, the pitch and roll attitudes of the ship were taken from the standard gauges on the bridge. The measured ship motion platform attitudes and ship datum attitudes are given in Table 4.

Table 4. Initial Attitudes of Ship Motion Platform and Ship Datum

	Pitch Attitude (deg)	Roll Attitude (deg)
Motion Platform	+ 0.2	+ 0.4
Ship Datum	- 0.5	+ 0.5

From Table 4, the instrumentation calibrations for the pitch and roll attitudes must be offset by the difference between the initial attitudes, i.e. a further 0.7 deg for pitch and 0.1 deg for roll.

To facilitate accurate repositioning of the mobile mast position at each grid point for all data runs, the flight deck was marked with yellow adhesive tape. Because the flight deck has a slope, the mast was at significantly different attitudes, with respect to the ship datum, for each of the grid points. At each grid point, the height of the mobile mast stabilising legs was adjusted and recorded so that the mast was nominally vertical (as indicated by spirit levels). This ensured that the measured airwake velocities could be related to the ship datum while the ship was in motion at sea.

Once the equipment was installed, a test run was made while the ship was still stationary at Garden Island dockyard in Sydney. As already indicated, this served as a practice run for the trials team and enabled baseline data to be obtained for a case without ship motion.

3.2 At Sea

Trial log sheets were supplied to the officer of the watch who recorded information on the sea conditions for each data run. The data recorded on the trial log sheets are summarised in Appendix B. One piece of information recorded on these is the sea state, which indicates the condition of the seas. The definition of sea state is given in Appendix C.

Prior to each data run, the trials team communicated with the bridge to ensure the desired relative wind conditions were achieved. When coloured smoke flares were set off for flow visualisation purposes, the bridge also had to transmit a message to vessels in the immediate area to let them know that the flares were not indicating an emergency.

It should be noted that some unforeseen circumstances arose during the trial, these being generally documented as comments in Appendix A. For example, the starboard cup anemometer failed after the first day at sea and was replaced by a spare. Thus when processing the data, the calibration for Cup 3 was used for data runs on the 16 and 18 September, and the calibration for Cup 1 was used thereafter. Also, for some of the strong relative wind cases, only eight of the thirteen data points were recorded because either it was thought that the wind would die down before a complete thirteen points could be achieved, or the ship could only maintain high speed for a limited time.[1] Another point is that the

[1] The amount of fuel carried by the ship was only sufficient (with required reserves) to reach the desired destination by the specified date. If high speeds were made over a lengthy period, the fuel consumption would be such that the ship would not be able to reach the destination. Also, for certain wind-over-deck conditions, the ship was forced to head away from New Zealand, and therefore had to make up the lost distance in order to dock by the specified date.

mobile mast was damaged as it was raised on the morning of the last day. This resulted in the lower anemometer array being twisted approximately 5 deg anti-clockwise when viewed from above.

4. PRELIMINARY DATA PROCESSING

To check for faulty data recorded during the trial, preliminary data processing was carried out for every recording. This consisted of simply applying the instrument calibrations and producing time histories of each channel with the output in imperial units. Any data that were corrupted could thus be detected at an early stage by observing which channels gave gross errors.

The data were transferred from the VADAR floppy disks to an Elxsi 6400 computer and then processed using program *SHIPREFINE*, which is a development of the program *REFINE* (Ref. 10) that includes additional code for notch digital filtering (Ref. 11) and non-linear calibrations for the Gill anemometers. The non-linear calibrations from Ref. 12 are shown in Table 5.

Table 5. Non-Linear Calibrations for Gill Anemometers

Propeller Frequency (Hz)	Airspeed/(Propeller Frequency) ($ft.s^{-1}.Hz^{-1}$) Into Wind Calibration	Airspeed/(Propeller Frequency) ($ft.s^{-1}.Hz^{-1}$) Away from Wind Calibration
25	0.0876	0.0948
50	0.0856	0.0915
75	0.0846	0.0902
100	0.0843	0.0892
150	0.0843	0.0886
200	0.0843	0.0886
500	0.0840	0.0886

Examination of the time histories shows that the data were of good quality, with some exceptions. Early in the trial it became apparent that the mid-level temperature probe (Channel 14) on the mobile mast was faulty, but no spares were available, and these data are unsalvageable. It is also apparent that, for some of the data runs, high frequency (HF) interference occurred from the HF emitters of the ship, affecting the digital channels. The digital inputs were single-ended coupled channels which were more susceptible to electromagnetic interference (EMI) than the differential coupled analogue channels.[1] Unfortunately, the aforementioned interference occurred throughout the case of a 20 kn relative wind from 90 deg to starboard. Since the digital channels indicate airwake flow direction, and at 90 deg relative wind the flow would be expected to be fairly steady, it is possible to apply simple logic and salvage these results, as discussed in Section 5.2.

5. DATA PROCESSING

The results obtained from the preliminary data processing discussed in Section 4 are inadequate for a number of reasons. Firstly, the tri-axial mounting of the Gill anemometers has a known non-cosinusoidal response to angle of attack variation (Ref. 13). The error obtained by vectorially adding the components can be over 10% for velocity magnitude and ± 5 deg for direction. An algorithm (documented in Ref. 13) may be applied to the three components which substantially reduces this error. Secondly, angular accelerations must be determined in order to correct accelerometer measurements for offset displacements of the accelerometers from the centre of gravity (Ref. 8).

After the preliminary data processing had been done, the Elxsi computer was retired. The data processing and associated output software were then modified to run on Macintosh personal

1 The VADAR system has since been modified to include differential line driver/receivers on all the digital input channels to reduce the possibility of EMI corrupting the data.

computers.[1] Program *MacShipRefine* is a development of *SHIPREFINE* which has been modified to correct the Gill anemometers for the previously mentioned non-cosinusoidal response to angle of attack variation, and to calculate angular accelerations by differentiation of angular rates.

5.1 Program *MacShipRefine*

Program *MacShipRefine* is run as shown below, bold italic type being user inputs and <CR> denoting a carriage-return. The input data file (for this example, `20091158.con`) and the calibration file `Shipcal` are required to be in the same directory as the program. The file `ShipCal`, with the details concerning instrumentation calibrations and the corrected anemometer channels, is given in Appendix D. The output file `20091158.DAT` may then be used as input to program *MacTrans* to obtain graphical and tabular output. Information on running *MacTrans* may be found in Ref. 15.

```
****************************************************
* Program to process data obtained from Ship motion *
* & anemometer trials on HMAS Darwin September 1989 *
*     using PC-based Data Acquisition System.       *
*     Data files must have ".CON"  extensions       *
*                  December 1989                    *
****************************************************

Input Data Filename (w/o ".Con" extension) = 20091158
Is this an aircraft data file (default N): N
".DAT" OUTPUT FILENAME (w/o ext) = <CR>
TITLE (2 lines of 60 chrs)
:Wind 60 deg, 20 kn - Position 10
:File 20091158 (filtered)
ARE ASSIGNED BLK NUMBERS REQRD : N
CALIBRATION FILENAME = shipcal
Day Number (Default is other than Day 1) = <CR>
IS PRE-PROCESSING WITH A NOTCH FILTER REQRD : N
OUTPUT INTERVAL (in 20'ths of sec; e.g. 40 for 2 sec) = <CR>
IS THE EXACT START TIME REQUIRED : N
STARTING TIME DELAY = <CR>
TIME LIMIT = <CR>
IS FILTERING REQRD : Y
IS OUTPUT OF FILTER CHARACTERISTICS REQRD : N
ARE DIGITAL FILTER DELAY ADJUSTMENTS REQRD : Y
IS SMOOTHING REQRD : N
ARE INSTRUMENT & ANALOGUE FILTER DELAY ADJUSTMENTS REQRD : N
ARE SCALES AND OFFSETS REQRD : Y
ARE PLOT LIMITS REQRD : N
ARE DROP-OUTS TO BE CORRECTED : N
ARE ALL CHANNELS REQRD : Y
DATE = 17-FEB-93
TIME = 10:11:28

No. time corrections =   0
No. blocks replaced =   0
No. drop-out corrections =   0

STOP 1
```

1 Processing software *SHIPREFINE* has been modified to become *MacShipRefine* (Ref. 14), and the general purpose output program *TRANS* has been modified to become *MacTrans* (Ref. 15).

5.2 Salvaging Corrupted Data

5.2.1 Problem Statement

As mentioned in Section 4, preliminary examination of the data showed that, during the case of a 20 kn relative wind from 90 deg to starboard, HF interference had corrupted the digital channels of the VADAR system. The role of the digital direction channels is to determine the wind velocity direction through the Gill anemometers (i.e. wind flowing into or out of the propeller) for the corresponding analogue channels which measure the wind velocity magnitude.[1] The wind velocity direction through the anemometer is important because the calibration is different for each direction. Table 6 gives the velocity direction channels and the corresponding velocity magnitude channels for each of the Gill anemometer arrays (Top, Mid, and Low). Note that the direction for Channel 28 is given by Channel 1 (an analogue channel) which was not affected by the interference.[2]

Table 6. Anemometer Direction and Magnitude Channels

Anemometer		Direction Channel	Magnitude Channel
Top (1)	*vertical*	33	20
Top (2)	*lateral*	34	21
Top (3)	*longitudinal*	35	22
Mid (4)	*vertical*	36	23
Mid (5)	*lateral*	37	24
Mid (6)	*longitudinal*	38	25
Low (7)	*vertical*	39	26
Low (8)	*lateral*	40	27
Low (9)	*longitudinal*	1	28

Table 7. Corrupted Digital Channels for 20 kn Wind at 90 deg

File Name	Deck Position	Channels Corrupted
21091409.con	1	33,34,35,36,37,38,39,40
21091406.con	3	none
21091403.con	5	34,35,37,38,40
21091412.con	7	34,35,36,37,38,39,40
21091415.con	8	34,35,37,38,40
21091418.con	9	34,35,37,38,40
21091424.con	11	34,35,36,37,38,39,40
21091421.con	13	34,35,37,38,40

The digital direction channels that were not operating correctly are indicated by a change in wind direction every time step. Since the Gill anemometers have a cut-off frequency of about 2.5 Hz, they

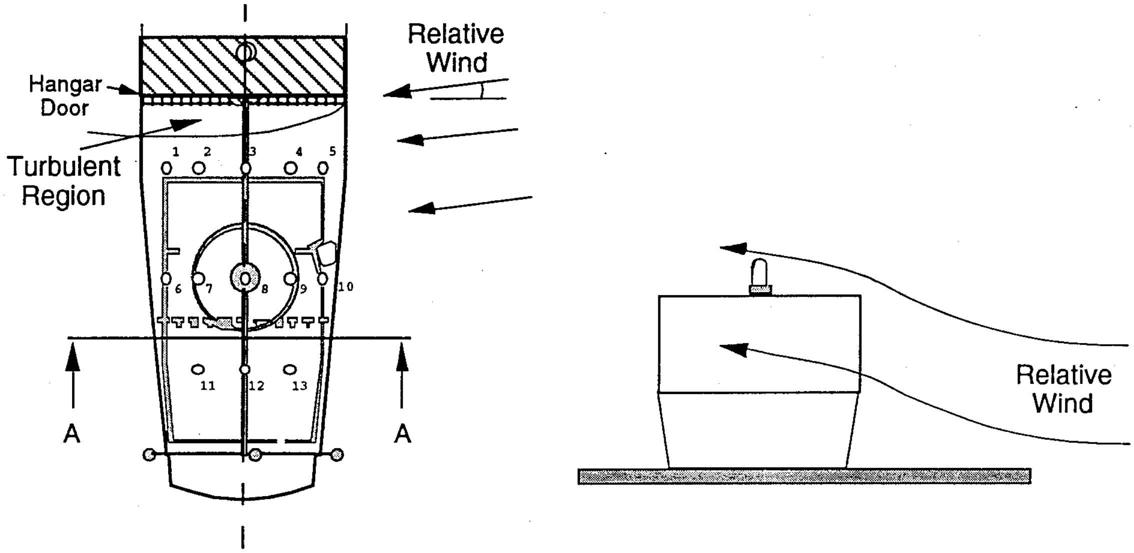
1 The actual magnitude is calculated from the measured data using a non-linear calibration included in program *MacShipRefine* (Table 5) which is dependent on the direction of the airflow.

2 The VADAR system has 8 digital and 32 analogue channels. Since the mobile anemometer mast was made up of 9 Gill anemometers, the direction for the 9th anemometer required the use of an analogue channel.

would therefore be incapable of sensing a change in wind direction every 0.05 second.[1] Table 7 shows which digital channels were corrupted for each deck position. It can be seen that during the course of the run (approximately 23 minutes), the particular digital channels that were corrupted at each deck position were not consistent, with position 3 having no channels corrupted.

5.2.2 Problem Solution

Since the relative wind was nominally from directly starboard, it would be expected that there would be a negligible effect on the airwake due to the ship superstructure over the flight deck. However, the ship anemometer indicated that the relative wind was slightly forward of 90 deg (between 80 and 86 deg). Figure 5 shows in general terms the expected flow over the flight deck.



Plan View

Section View A-A

Figure 5. Expected Airwake Over Flight Deck

When directional data for any of the vertical Gill anemometers were corrupted, the airwake was assumed to have an upward component (i.e. out of the propeller). For the lateral and longitudinal anemometers, the airwake was assumed to be into the propellers. These assumptions should hold true over most of the flight deck, although the positions near the hangar could be in relatively unstable flow, where the direction may fluctuate. This may be checked by examining the data after the directions have been set. If the absolute velocity is much greater than zero the assumptions are probably correct. However, if the velocities approach zero, the direction may be varying, so the corrected data must be treated with some caution.

5.2.3 Modifications to Program *MacShipRefine*

The Fortran source files for program *MacShipRefine* are given in Table 8. The program is compiled and linked by the Language Systems Fortran makefile 'MacShipRefine.make'.

[1] At low velocities, the propeller of the Gill anemometer may be oscillating and thus the direction channels may indicate a change in direction in successive time steps. The magnitude of the airwake velocity should therefore be examined first to avoid erroneously assuming the data are corrupted.

Table 8. Source Files for Program MacShipRefine

ShipR1.f	ShipR6.f	TSub87.f
ShipR2.f	Rename.f	SPreNotch.f
ShipR3.f	Rextra.f	NotchFilter.f
ShipR4.f	ChkUpr.f	Gillfix.f
ShipR5.f	Ding.f	FindStartTime.f

Subroutine *PropCal*, which is found in module `ShipR4.f`, reads the directional channels that determine the value of parameter `Flag`[1] for each of the anemometers. This parameter is then passed to Subroutine *Interp*, which returns the calibration constant for the given frequency and direction of propeller rotation. For those cases where the digital channel was corrupted, parameter `Flag` was set constant to either zero or one. Four different versions of subroutine *PropCal* are required to allow for the different combinations of corrupted digital channels indicated by Table 7. A summary of the modified modules corresponding to each deck position is given in Table 9.

Table 9. Position Specific MacShipRefine Modules

Deck Position	Module
1	ShipR4(mod3).f
3	ShipR4.f
5	ShipR4(mod1).f
7	ShipR4(mod2).f
8	ShipR4(mod1).f
9	ShipR4(mod1).f
11	ShipR4(mod2).f
13	ShipR4(mod1).f

Table 10 summarises the value given to parameter `Flag` for each direction channel in each of the modified `ShipR4` modules detailed in Table 9. Note that no changes to the value of `Flag` indicates that `Flag` is determined from reading the appropriate digital direction channel.

Table 10. Modifications To Digital Direction Channels

Channel	Anemometer	ShipR4(mod1).f	ShipR4(mod2).f	ShipR4(mod3).f
33	Top (1)	none	none	Flag=1
34	Top (2)	Flag=0	Flag=0	Flag=0
35	Top (3)	Flag=0	Flag=0	Flag=0
36	Mid (4)	none	Flag=1	Flag=1
37	Mid (5)	Flag=0	Flag=0	Flag=0
38	Mid (6)	Flag=0	Flag=0	Flag=0
39	Low (7)	none	Flag=1	Flag=1
40	Low (8)	Flag=0	Flag=0	Flag=0

1 `Flag` = 0 indicates wind into propeller; `Flag` = 1 indicates wind out of propeller.

Upon examination of the salvaged data, it was apparent that only one data file (21091409) included data approaching zero, indicating that the airwake direction may have been fluctuating. This is because the mast position which provided the data for this file (position 1) is in the area that is more likely to contain turbulent flow (Fig. 5). While the data for the majority of mast positions must be treated with caution, the data for position 1 are more likely to be in error.

6. FURTHER DATA PROCESSING

Although the ship was operating under calm sea conditions during most of the trial, a degree of ship motion is still present in the measured wind data. The long moment arms of the anemometer masts (Figs 2 and 3) also tend to exaggerate the motion. Figure 6 shows a dimensioned elevation of an FFG–7 with an estimated position of the centre of ship motion given as approximately half of the water-line length of the ship from the bow. The technique adopted for determining the ship motion and then removing these effects from the airwake measurements is discussed fully in Reference 8.

Reference 16 describes the graphical display program *ffgView*, which is used to determine mean flow of the airwake from time histories generated by *MacTrans*. Program *ffgView* also displays the mean flow of the airwake over the flight deck of an FFG-7 using data from the ship trial or AOD wind tunnel tests (Ref. 17). The full airwake results of the ship trial, including mean flow given by *ffgView* as well as turbulence spectra, are detailed in Reference 9.

7. CONCLUDING REMARKS

A ship motion and airwake trial has been carried out aboard an 'Adelaide' class FFG-7 frigate. Data processing procedures have been described which take the raw measured data from the VADAR system, convert them to imperial units, and correct the Gill anemometer data for non-cosinusoidal response to angle-of-attack variation. A method of salvaging data corrupted by HF signals has also been presented, along with a discussion of further data processing required to enable the results to be used as a data base for a computer simulation of the Sikorsky S-70B-2 and FFG-7 combination.

ACKNOWLEDGEMENTS

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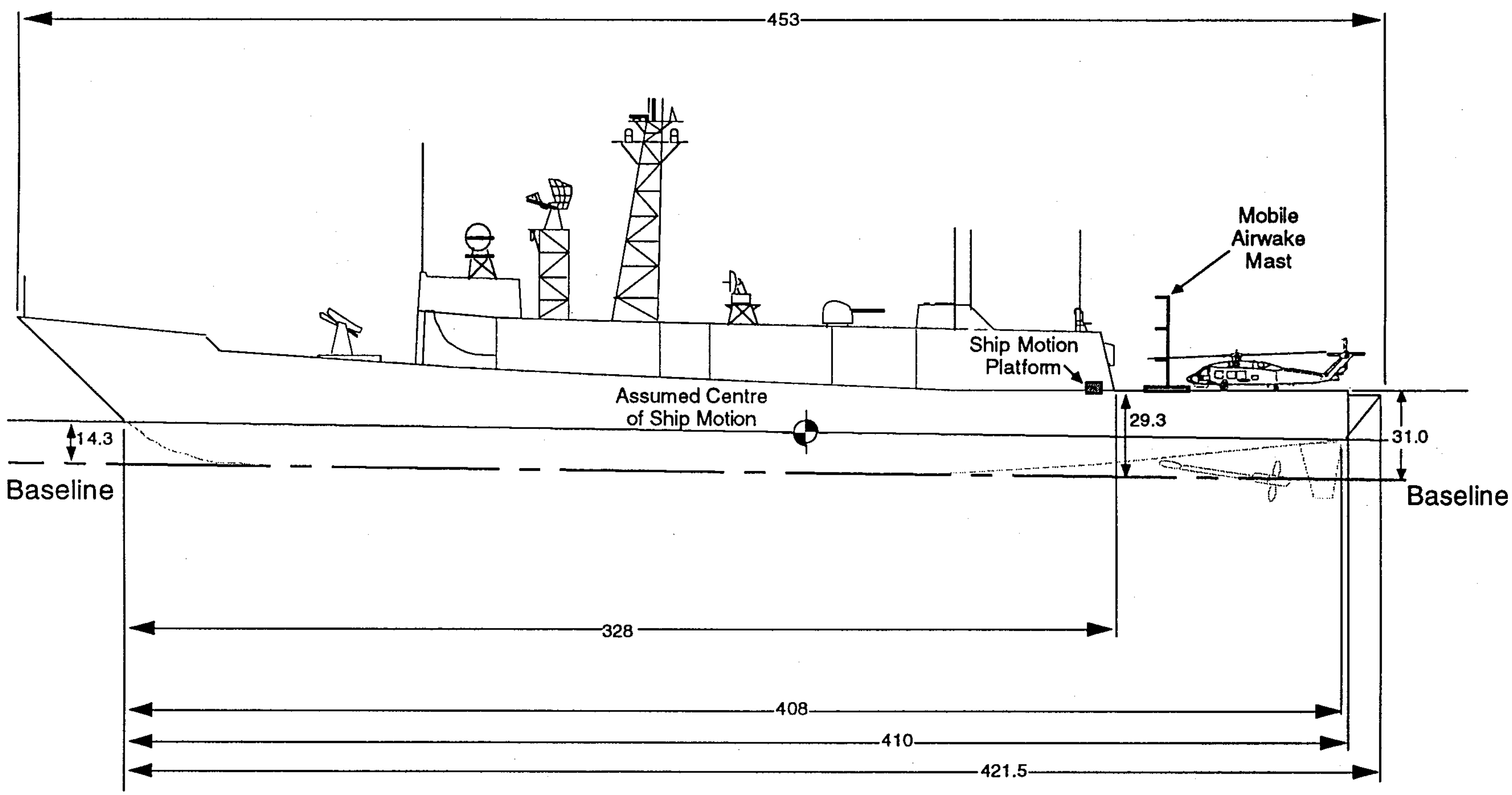

Figure 6. FFG-7 Elevation (All Dimensions in ft)

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APPENDIX A - RECORD INFORMATION, HMAS DARWIN, SEPTEMBER 1989

Included here is the correlation between the data file names of the data recorded on VADAR and the relative wind conditions for each measured data file. The position numbers in Tables A1 to A7 refer to the position of the mobile anemometer array on the flight deck, as shown in Figure 4.

Table A1. Ship Alongside

(Gangway in the way for Position 1)

Pos'n No.	Filename
1	16091543.DAT
2	16091546.DAT
3	16091549.DAT
4	16091553.DAT
5	16091557.DAT
6	16091533.DAT
7	16091537.DAT
8	16091506.DAT
9	16091510.DAT
10	16091515.DAT
11	16091528.DAT
12	16091524.DAT
13	16091520.DAT

Table A2. Relative Wind From Ahead

Pos'n	File Name		
No.	10 kn [1]	20 kn	35 kn [2]
1	19091116.DAT	19091654.DAT	19091719.DAT
2	19091120.DAT	19091657.DAT	
3	19091124.DAT	19091701.DAT	19091717.DAT
4	19091128.DAT	19091704.DAT	
5	19091132.DAT	19091621.DAT	19091714.DAT
6	19091108.DAT	19091647.DAT	
7	19091112.DAT	19091651.DAT	19091722.DAT
8	19091046.DAT	19091624.DAT	19091725.DAT
9	19091050.DAT	19091628.DAT	19091729.DAT
10	19091053.DAT	19091632.DAT	
11	19091105.DAT	19091644.DAT	19091734.DAT
12	19091101.DAT	19091640.DAT	
13	19091057.DAT	19091636.DAT	19091731.DAT

1 Starboard cup anemometer shorted; replaced Cup 1 with Cup 3. Channel A31 (aerovane) inoperative.

2 Limited time available required recording times reduced to 60 s (rather than 90 s) and only eight mobile mast positions.

Table A3. Relative Wind 30 Deg to Starboard

Pos'n No.	File Name		
	10 kn	20 kn	35 kn [1]
1	20091451.DAT	18091452.DAT	21091315.DAT
2	20091454.DAT	18091455.DAT	21091318.DAT
3	20091457.DAT	18091458.DAT	21091321.DAT
4	20091500.DAT	18091502.DAT	21091325.DAT
5	20091421.DAT	18091505.DAT	21091328.DAT
6	20091445.DAT	18091443.DAT	21091307.DAT
7	20091448.DAT	18091446.DAT	21091311.DAT
8	20091424.DAT	18091420.DAT	21091243.DAT
9	20091428.DAT	18091424.DAT	21091247.DAT
10	20091431.DAT	18091428.DAT	21091252.DAT
11	20091442.DAT	18091439.DAT	21091303.DAT
12	20091438.DAT	18091435.DAT	21091300.DAT
13	20091435.DAT	18091432.DAT	21091255.DAT

Table A4. Relative Wind 60 Deg to Starboard

Pos'n No.	File Name	
	10 kn	20 kn
1	18091554.DAT	20091220.DAT
2	18091558.DAT	20091223.DAT
3	18091601.DAT	20091227.DAT
4	18091605.DAT	20091231.DAT
5	18091517.DAT	20091234.DAT
6	18091546.DAT	20091213.DAT
7	18091550.DAT	20091216.DAT
8	18091521.DAT	20091237.DAT
9	18091525.DAT	20091155.DAT
10	18091529.DAT	20091158.DAT
11	18091541.DAT	20091209.DAT
12	18091537.DAT	20091205.DAT
13	18091533.DAT	20091202.DAT

[1] Mast bent upon raising; lower anemometer array twisted approximately 5 deg anticlockwise viewed from above.

Table A5. Relative Wind 90 Deg to Starboard

Pos'n No.	File Name 10 kn [1]	File Name 20 kn [2]
1	18091700.DAT	21091409.DAT
2	18091704.DAT	
3	18091708.DAT	21091406.DAT
4	18091617.DAT	
5	18091621.DAT	21091403.DAT
6	18091652.DAT	
7	18091656.DAT	21091412.DAT
8	18091626.DAT	21091415.DAT
9	18091631.DAT	21091418.DAT
10	18091635.DAT	
11	18091648.DAT	21091424.DAT
12	18091644.DAT	
13	18091640.DAT	21091421.DAT

Table A6. Relative Wind 135 deg to Starboard at 10 kn

Pos'n No.	File Name
1	20091337.DAT
2	20091340.DAT
3	20091343.DAT
4	20091347.DAT
5	20091350.DAT
6	20091330.DAT
7	20091334.DAT
8	20091307.DAT
9	20091311.DAT
10	20091315.DAT
11	20091326.DAT
12	20091323.DAT
13	20091319.DAT

Table A7. Relative Wind 180 deg to Starboard at 10 kn

Pos'n No.	File Name
1	20090937.DAT
2	20090940.DAT
3	20090943.DAT
4	20090947.DAT
5	20090950.DAT
6	20090930.DAT
7	20090933.DAT
8	20090956.DAT
9	20091000.DAT
10	20090916.DAT
11	20090927.DAT
12	20090923.DAT
13	20090920.DAT

1 Wind unstable; sometimes 45 deg to starboard.

2 Wind was thought likely to drop below that required to maintain 20 kn relative wind so recording time was reduced from 90 s to 60 s and number of mast positions reduced to eight.

APPENDIX B - TRIAL LOG SHEET INFORMATION

Date	Ship Time	Ship Speed (kn)	Ship Hdg (deg)	Wind Speed (kn)	Wind[1] Dirn (deg)	Ship Anem	Sea State	Wave Dirn (deg)	Comments
18/9/89	1405	15	115	20	30	Port	2-3	215	Rel wind speed gusting to 22-23 kn ~ every 5 mins. Sea swell from 215 deg, av wave height 0.4 m, occasionally 0.5 to 0.6 m. Few white horses, wind waves confused 0.1 - 0.2 m. Generally calm.
18/9/89	1520	10	070	10	60	Port	2-3	215	Rel wind speed gusting to 13 kn occasionally, seas as above
18/9/89	1613	6	060	7	90	Port	2	210	Rel wind speed gusting to 9 kn, swell from 210, av wave height 0.5 m, wind waves confused. Wind abating
19/9/89	1100	20	075	10	0	Port	2	210	True wind speed 9 kn from 258 deg, sea light with small waves, some white horses beginning to appear
19/9/89	1612	9	250	20	0	Port	2-3	220	Confused swell mainly from 220, av wave height 0.5 m, occasional wind waves 0.1 to 0.2 m on swells.
19/9/89	1714	24.5	240	35	0	Port	2-3	225	Rel wind speed sometimes falling to 32 kn for ~ 30 s, av wave height 0.4 to 0.6 m, wind waves as above, ship pitching ± 3 deg due to high ship speed
20/9/89	0920	8	104	10	180	Stbd	3	240	Rel wind speed varying 8 to 12 kn, swell av wave height 1.2 m, rain squalls with associated gusts, trial aborted due to wind abating
20/9/89	1015	4	070	10	180	Stbd	3	255	Wind variable due to surrounding rain squalls, swell av wave height 1.0 m, trial repeat of above
20/9/89	1242	10	160	20	60	Port	3	260	Minor fluctuations in wind speed, swell on stbd beam av wave height 1.5 m
20/9/89	1344	7	100	10	135	Stbd	2-3	230	True wind speed 16 kn from 250 ± 5 deg, swell av height 1.0 m
20/9/89	1510	24	098	10	30	Stbd	2-3	220	True wind speed 15 kn from 258 deg , swell 0.5 to 1 m
21/9/89	1445	18	085	35	30	Stbd	4	300	True wind speed 19 kn from 141 deg, moderate sea, well formed swell, wind variable through passing showers
21/9/89	1600	4	015	20	90	Stbd	3	290	True wind speed 21 kn at 115 deg, regular swell at 0.75 m wave height, wind variable ± 3 kn, ± 10 deg

[1] Wind direction is relative to the ship, e.g. the wind is 30 degrees off the starboard bow for the first case.

APPENDIX C - SEA STATE

Reproduced from Reference 18.

Table C1. Sea States

Sea State Code	Waveheight (m)	Description
0	0	Calm (glassy)
1	0 to 0.1	Calm (rippled)
2	0.1 to 0.5	Smooth (wavelets)
3	0.5 to 1.25	Slight
4	1.25 to 2.5	Moderate
5	2.5 to 4.0	Rough
6	4 to 6	Very Rough
7	6 to 9	High
8	9 to 14	Very High
9	Over 14	Phenomenal

APPENDIX D - DATA CALIBRATION FILE 'SHIPCAL'

TITLE (2 lines of 60 chrs)
Calibration file for HMAS Darwin motion/airwake
trials, September 1989 - Cal gives Eng units
[Channel no. -1 denotes time]

Channel No.	Label	Cal Factor, Offset	Assigned No.	Plot Limits (Lower,Upper)	Filter Characteristics (Freq, Atten) (No. Poles)	Smoothing Characteristics (No. Pts Smoothed) (No. Params)	Notch Filter Characteristics (Alpha, dF) (Min Freq., Max Freq., Exp Freq.)
-1	Time (s)	5.0000E-02 0.0000E+00					
1	Wind Dirn Low (9)	2.4410E-03 0.0000E+00	18	0.0000E+00 5.0000E+00			
2	Roll Acc (deg/s/s)	1.0000E+00 0.0000E+00	653	-1.0000E+01 1.0000E+01			
3	Pitch Acc (deg/s/s)	1.0000E+00 0.0000E+00	654	-1.0000E+01 1.0000E+01			
4	Yaw Acc (deg/s/s)	1.0000E+00 0.0000E+00	655	-1.0000E+01 1.0000E+01			
5	Pitch Att (deg)	1.8997E-02 -5.6590E-02	32	-5.0000E+00 5.0000E+00			
6	Roll Att (deg)	1.8872E-02 -3.5140E-02	33	-5.0000E+00 5.0000E+00			
7	Pitch Rate (deg/s)	3.7996E-03 -1.0965E+00	35	-5.0000E+00 5.0000E+00	4.5000E+00 5.0000E+01 5		0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
8	Roll Rate (deg/s)	5.7974E-03 -2.4480E-01	36	-5.0000E+00 5.0000E+00	4.5000E+00 5.0000E+01 5		0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
9	Yaw Rate (deg/s)	3.2910E-03 -3.0600E-02	37	-5.0000E+00 5.0000E+00	4.5000E+00 5.0000E+01 5		0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
10	Vert Acc (ft/s/s)	3.5464E-02 5.0840E-01	38	2.5000E+01 3.5000E+01			
11	Lat Acc (ft/s/s)	2.3624E-02 3.3870E-01	39	-5.0000E+00 5.0000E+00			
12	Lon Acc (ft/s/s)	2.7456E-02 9.3710E-02	40	-5.0000E+00 5.0000E+00			
13	Temprature Top (C)	4.9890E-02 -1.8667E+00	19	1.0000E+01 3.0000E+01			
14	Temprature Mid (C)	5.3435E-02 -2.5095E+00	20	1.0000E+01 3.0000E+01			
15	Temprature Low (C)	5.1282E-02 -8.1100E-02	21	1.0000E+01 3.0000E+01			
16	Port Cup Vel (ft/s)	7.5291E-02 5.0767E+00	52	0.0000E+00 1.0000E+02			
17	Port Cup Dirn (deg)	2.2972E-01 -1.7577E+02	53	-1.8000E+02 1.8000E+02			
18	Stbd Cup Vel (ft/s)	7.6025E-02 4.1778E+00	54	0.0000E+00 1.0000E+02			
19	Stbd Cup Dirn (deg)	2.0985E-01 -1.7964E+02	55	-1.8000E+02 1.8000E+02			

20	Wind Vel	2.4410E-03	1	0.0000E+00
	Top (1)	0.0000E+00		5.0000E+00
21	Wind Vel	2.4410E-03	2	0.0000E+00
	Top (2)	0.0000E+00		5.0000E+00
22	Wind Vel	2.4410E-03	3	0.0000E+00
	Top (3)	0.0000E+00		5.0000E+00
23	Wind Vel	2.4410E-03	4	0.0000E+00
	Mid (4)	0.0000E+00		5.0000E+00
24	Wind Vel	2.4410E-03	5	0.0000E+00
	Mid (5)	0.0000E+00		5.0000E+00
25	Wind Vel	2.4410E-03	6	0.0000E+00
	Mid (6)	0.0000E+00		5.0000E+00
26	Wind Vel	2.4410E-03	7	0.0000E+00
	Low (7)	0.0000E+00		5.0000E+00
27	Wind Vel	2.4410E-03	8	0.0000E+00
	Low (8)	0.0000E+00		5.0000E+00
28	Wind Vel	2.4410E-03	9	0.0000E+00
	Low (9)	0.0000E+00		5.0000E+00
29	Mast Pitch	-1.3262E-02	30	-5.0000E+00
	(deg)	2.7310E-01		5.0000E+00
30	Mast Roll	-1.3247E-02	31	-5.0000E+00
	(deg)	1.8250E-01		5.0000E+00
31	Aerovane	5.7464E-02	601	0.0000E+00
	Vel (ft/s)	3.4393E+00		1.0000E+02
32	Aerovane	2.3551E-01	602	-1.8000E+02
	Dirn (deg)	-1.5310E+02		1.8000E+02
33	Wind Dirn	1.0000E+00	10	-1.0000E+00
	Top (1)	0.0000E+00		1.0000E+00
34	Wind Dirn	1.0000E+00	11	-1.0000E+00
	Top (2)	0.0000E+00		1.0000E+00
35	Wind Dirn	1.0000E+00	12	-1.0000E+00
	Top (3)	0.0000E+00		1.0000E+00
36	Wind Dirn	1.0000E+00	13	-1.0000E+00
	Mid (4)	0.0000E+00		1.0000E+00
37	Wind Dirn	1.0000E+00	14	-1.0000E+00
	Mid (5)	0.0000E+00		1.0000E+00
38	Wind Dirn	1.0000E+00	15	-1.0000E+00
	Mid (6	0.0000E+00		1.0000E+00
39	Wind Dirn	1.0000E+00	16	-1.0000E+00
	Low (7)	0.0000E+00		1.0000E+00
40	Wind Dirn	1.0000E+00	17	-1.0000E+00
	Low (8)	0.0000E+00		1.0000E+00
41	Crctd Wind	1.0000E+00	603	-2.0000E+01
	Top1 (ft/s	0.0000E+00		2.0000E+01
42	Crctd Wind	1.0000E+00	604	-2.0000E+01
	Top2 (ft/s	0.0000E+00		2.0000E+01

43	Crctd Wind	1.0000E+00	605	-2.0000E+01
	Top3 (ft/s	0.0000E+00		2.0000E+01
44	Crctd Wind	1.0000E+00	606	-2.0000E+01
	Mid1 (ft/s	0.0000E+00		2.0000E+01
45	Crctd Wind	1.0000E+00	607	-2.0000E+01
	Mid2 (ft/s	0.0000E+00		2.0000E+01
46	Crctd Wind	1.0000E+00	608	-2.0000E+01
	Mid3 (ft/s	0.0000E+00		2.0000E+01
47	Crctd Wind	1.0000E+00	609	-2.0000E+01
	Low1 (ft/s	0.0000E+00		2.0000E+01
48	Crctd Wind	1.0000E+00	610	-2.0000E+01
	Low2 (ft/s	0.0000E+00		2.0000E+01
49	Crctd Wind	1.0000E+00	611	-2.0000E+01
	Low3 (ft/s	0.0000E+00		2.0000E+01
50	Exact	1.0000E+00	612	0.0000E+00
	Start Time	0.0000E+00		1.2000E+02
51	Ship Dirn	5.4932E-03	613	-1.8000E+02
	(deg)	0.0000E+00		1.8000E+02
52	Ship Vel	6.1035E-04	614	0.0000E+00
	(kn)	0.0000E+00		4.0000E+01
53	Ship Anem	1.5259E-03	615	0.0000E+00
	Vel (kn)	0.0000E+00		4.0000E+01
54	Ship Anem	5.4932E-03	616	0.0000E+00
	Dirn (deg)	0.0000E+00		3.6000E+02
55		0.0000E+00		
		0.0000E+00		
56		0.0000E+00		
		0.0000E+00		
57		0.0000E+00		
		0.0000E+00		
58		0.0000E+00		
		0.0000E+00		

EXCEPTIONS

Channel No.	Flight No.	Cal Factor	Offset
18	1	7.3103E-02	7.3985E+00
19	1	2.2892E-01	-1.7422E+02

DSTO-TR-0039
FFG-7 Ship Motion and Airwake Trial:
Part I - Data Processing Procedures

A.M. Arney

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A trial to measure ship motion and airwake has been carried out aboard an 'Adelaide' class FFG-7 frigate. Data processing procedures are described which take the raw measured data from the data acquisition system, convert them to imperial units, and correct the Gill anemometer data for non-cosinusoidal response to angle-of-attack variation. A method of salvaging data corrupted by high frequency signals is also presented, along with a discussion of further data processing required to enable the results to be used as a data base for a computer simulation of the Sikorsky S-70B-2 helicopter and FFG-7 combination.

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